Passive Infrared Signature Augmentation of Full-Scale Plastic Targets

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ABSTRACT

The Targets Management Office (TMO) manages the development, acquisition, and operation of both aerial and ground target systems for use in destructive and non-destructive testing by the U.S. Army T&E community. A need has been identified for low-cost, full-scale validated targets that can accurately simulate the visual, infrared (IR), and radar signatures of threat systems. To address this need, a program was initiated by TMO to augment an existing full-scale, vacuum-formed plastic target with sufficient signature fidelity to adequately stress U.S. Weapon System sensors. This paper discusses the portion of the program dealing with the development of a passive IR system to meet signature needs. The concept presented in this paper will detail a cost effective design solution that augments the plastic targets with passive thermal properties that emulate actual vehicle armor throughout the diurnal cycle.

The chosen solution for passive IR signature emulation was the addition of water jackets to these plastic targets to replicate the thermal mass of actual armor. This technology not only is an affordable approach to improving the passive signature of the existing plastic target, but also is easily supportable on a test site. The water jacket concept has previously been proven in the BMP-3 Surrogate program. In this program, the amount of water necessary to imitate the thermal mass of the actual target was calculated. Trade studies were then conducted between signature fidelity and structural integrity to arrive at a solution that would provide sufficient IR signature while still allowing for the plastic target to support the additional weight of the water. The combined weight of the plastic shell and water jackets is significantly less than that of the actual target, but the plastic target has an effectively equivalent thermal mass of a heavily armored vehicle.

The process for implementing water jacket technology on plastic range targets is presented. Modeling and simulation techniques were prevalent in this program. A meshed model of the plastic target was created and material properties and thicknesses of both the shell and water jackets were incorporated into this model. Thermal simulations were then conducted to compare the thermal properties of the plastic target to actual vehicle thermal properties in order to achieve the optimal placement and configuration of the water jackets on the plastic target. A sub-structure support system was then designed to withstand the load of the water jackets. The water jackets were then fabricated and attached to the plastic shell, and field-tests were conducted to verify the signature fidelity and structural integrity of the surrogate target. IR signature comparisons of the surrogate against the actual threat target are presented to demonstrate the feasibility of this approach.

INTRODUCTION

The Targets Management Office (TMO), Project Manager for Instrumentation, Targets, and Threat Simulators (PM-ITTS), U.S. Army Simulation, Training and Instrumentation Command (STRICOM), is responsible for the development of ground targets for weapon system testing. The requirements for the targets are customer driven and many times these requests are for full-scale, low cost targets that accurately represent the visual, infrared and radar signatures of threat systems. In order to accurately stress the weapon systems, it is crucial to have a ground target that is a correct representation of the intended threat system.

The Naval Air Warfare Center Atlantic Targets and Marine Operations of Patuxent River Naval Base has developed a low-cost vacuum forming process to fabricate a variety of plastic armored vehicle targets. These surrogate targets support a wide range of testing and training requirements. The targets are created out of 5/32" thick ABS plastic sheets and the plastic is available in either olive or desert sand or can be painted in camouflage colors. The vehicles are usually mounted on skids and can easily be towed behind a pickup truck. Visually, these targets are an accurate representation of the actual target for which they are modeled after. Figure 1 shows a photograph and a thermal image of the T-72 plastic target.

Figure 1. Vacuum-formed plastic T-72 photograph and thermal image.

The plastic ground targets meet the requirements of being a low-cost, visually representative target. In addition to being visually representative, TMO customers require a degree of IR and radar signature accuracy to effectively stress their sensor systems. This paper will concentrate solely on emulating the passive IR signature. The plastic targets created at the Patuxent River Naval Base need to be augmented in order to correctly simulate the passive IR signature of the actual vehicle. The augmentation process consists of the addition of water jackets to the underside of the plastic targets to replicate the thermal mass of thick armor present on an actual threat system.

Currently the plastic targets can be augmented to provide an active IR signature of the engines running and the barrel heated from recent gun flash. The thermal image in Figure 1 is of the plastic target with the active signature augmentation hardware in operation. This augmentation is the result of heating elements added to areas of the target such as the exhaust port, wheels, and gun barrel. The heating elements are used to represent the target in specific exercised conditions, but aren't capable of accurately portraying the vehicle when outside factors such as, time of day, wind and solar loading become of interest. The existing augmentation process neglects representation of the thermal mass of the target, which is important in simulating a correct IR signature. The water jacket augmentation process will generate a passive IR signature that is responsive to the effects of the surrounding environment, much the same as an actual vehicle would respond under natural conditions. The threat system of interest for this program is the T-72 main battle tank. The thick armor of the T-72 has a large thermal mass. The temperatures of objects with large thermal masses will respond more slowly than plastic to natural heat inputs such as wind and solar loading. Therefore, the thermal mass of a target must be replicated in order to match surface temperatures over the course of a day and in different environmental states.

The process for implementing water jacket technology on plastic range targets is shown in Figure 2. This process includes creating the vehicle geometry, creating a meshed model, attributing it with material properties, calculating and adding water jacket thicknesses, and running a thermal simulation to compare the augmented plastic target model to an actual vehicle model. After the thermal simulations are completed and the water jacket thickness is determined, a sub-structure support system is then designed to withstand the calculated weight of the water jackets. Each water jacket is then fabricated and attached to the pre-existing plastic shell. Field-tests are then conducted to verify the signature fidelity of the surrogate against the actual target.

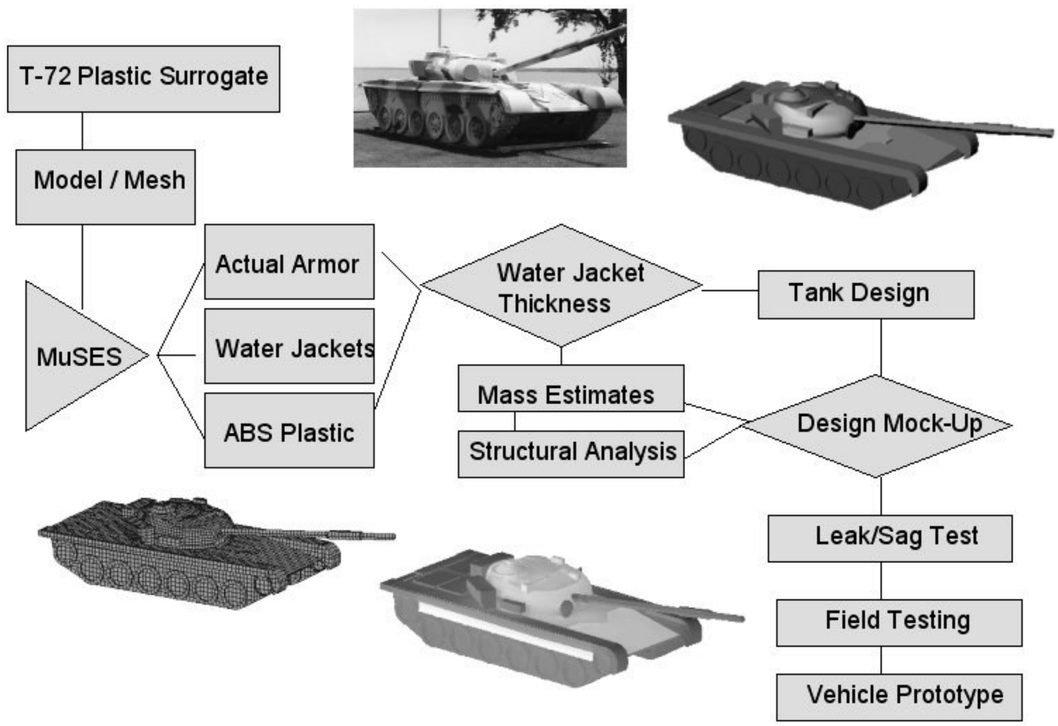

Figure 2. Plastic target augmentation process.

AUGMENTATION PROCESS

The entire process for designing water jackets begins with determining which sections of the plastic target require a water jacket to accurately simulate the thermal mass of the actual target. Thicker sections retain heat longer and therefore require thicker water jackets to simulate their thermal mass. Thinner sections, such as the gun barrel, fender skirts and turret boxes, do not require water jackets. After analysis of the T-72, the following sections require water jackets to simulate their thermal mass: glacis, hull sides, hull top, hull rear, turret top, turret front and sides, and turret rear. These locations are shown in Figure 3.

The critical parameter for the augmentation process is the thickness of the water jacket. Since the length and width of the water jacket and armor section have to remain the same, the thickness needs to be calculated to yield an equivalent heat capacity for the appropriate volume of the actual material. The derivation of the equations used to calculate the water jacket thickness has been published previously. [1]

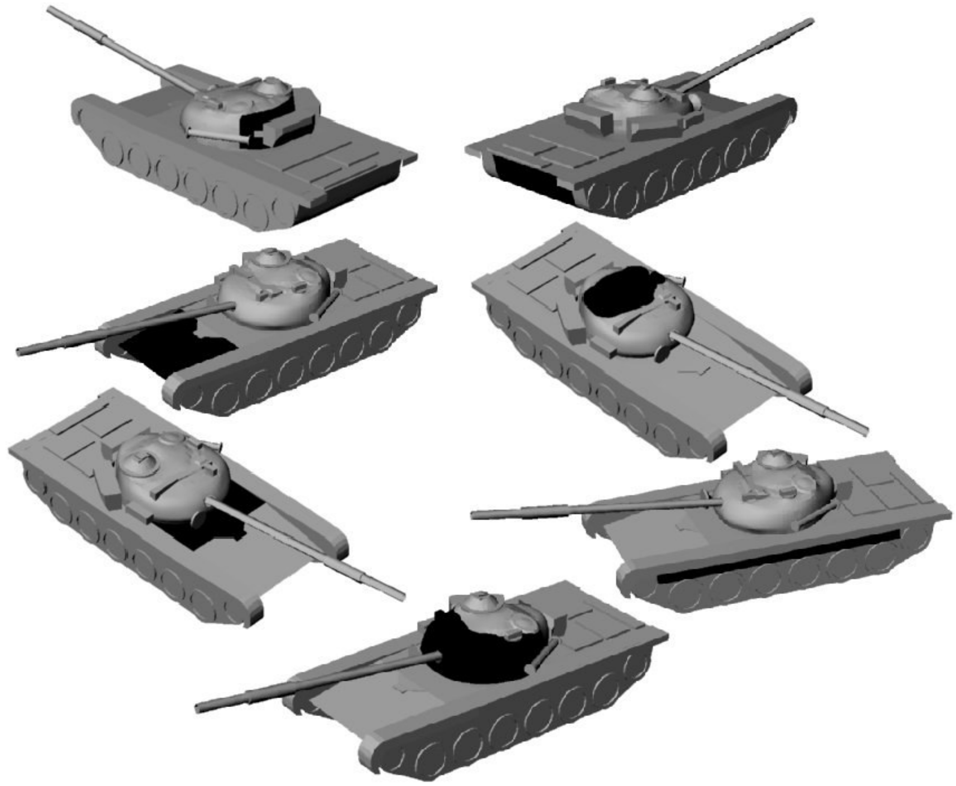

Figure 3. Water jacket locations.

The goal of the calculation is to determine what amount of water is necessary to emulate the thermal mass of actual armor. Given the composition of the actual armor, the density and specific heat of the material(s) must be known in order to complete the calculations. The water jacket wall thickness is governed by the thickness of the material used to build the tank. The water jackets of the T-72 are vacuum formed from the same material as the pre-existing plastic surrogate shell. This material is 5/32" ABS plastic. For the purposes of calculation, the imperfect thermal conduction between the ABS and water is ignored and the heat capacity of the ABS and water is calculated as a thermally homogeneous mass. The thickness of the water is the only unknown. The water thickness can be calculated by the following equation:

$$d_{water} = \frac{d_{armor} \cdot \rho_{armor} \cdot C_{parmor} - 2 \cdot d_{ABS} \cdot \rho_{ABS} \cdot C_{pABS}}{\rho_{water} \cdot C_{pwater}} \tag{1}$$

where d_{water} is the water thickness, d_{armor} is the armor thickness, ρ_{armor} is the density of the armor, Cp_{armor} is the specific heat of the armor, d_{ABS} is the thickness of the ABS, Cp_{ABS} is the specific heat of the ABS, ρ_{water} is the density of the water, and Cp_{water} is the specific heat of the water.

The next step in developing water jackets for the plastic surrogate is to create a computer model of the target. Dimensions for the model were taken from an existing plastic surrogate located at Redstone Arsenal. The turret was based on a full-scale actual T-72 model that was previously created. The model generated is a simplified version of the plastic surrogate. Details, such as the grating on the radiator and additions to the glacis, were left off. By decreasing the amount of unnecessary detail, the time to complete a thermal simulation decreases.

Once the model is completed, it is properly meshed to allow for conductive heat transfer between thermal nodes. The meshed model is imported into the Multi-Service Electro-optic Signature (MuSES) code and each part is attributed with the appropriate material properties and thicknesses. The vehicle model is attributed as the actual target, as a plastic shell, and with water jackets to determine the improvement the water jackets make over the pre-existing plastic surrogate and to determine how close the water jacketed target is to the actual target. Several simulations are run in MuSES under different weather conditions to indicate how the vehicle reacts under various solar loads. For this reason, both cloudy day and sunny day weather files are run in simulations. The results from the simulations are compared for each part and the improvements are quantified. After the results of the simulation are evaluated, the optimal thickness for the water jacket can be determined. Trade studies are conducted between signature fidelity and structural integrity to arrive at a solution that provides sufficient IR signature fidelity while still allowing for the plastic target to support the additional weight of the water.

With the thickness of the water jacket finalized, the additional mass of the water can be calculated. This is accomplished by knowing the density of water and the volume of each water jacket. The mass of the water jacket assembly is critical in designing the supporting framework. The supporting structure is designed using common lumber and fasteners. This keeps the materials both inexpensive and easily accessible. The design of the structure is made to be as simple as possible for ease of assembly, yet strong enough to safely support the load from the water.

Once all the design work is completed, the plans can be given to the fabrication shop so the parts can be fabricated. The first step to fabricating the water jacket is to build a mold in the shape of the jacket. The mold is built out of layers of dense particleboard. Each mold has to be extremely strong to withstand the pressure from the vacuum forming process. Large sheets of ABS plastic are vacuum formed around the molds to create the shape of the water jacket. The particleboard is porous enough to allow the vacuum to pull air through it. Once the mold is formed from the ABS sheet, the excess material is cut away, leaving the desired water jacket. The exterior plastic parts are also created in this manner. Examples of the molds can be seen in Figure 4.

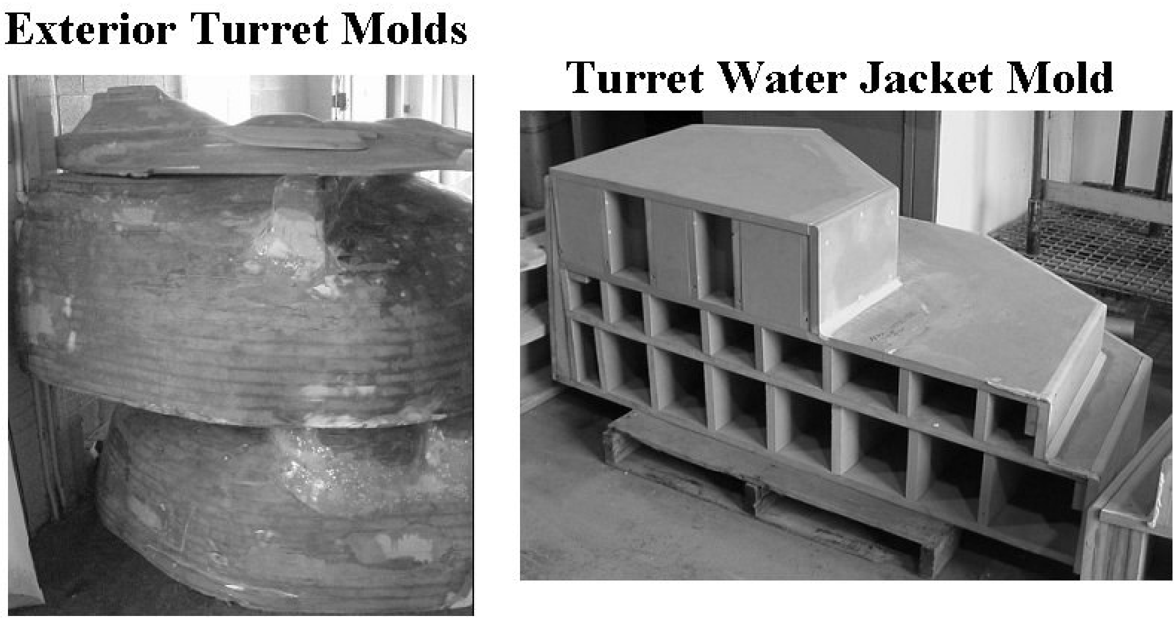

Figure 4. Vacuum forming process molds.

The water jacket molds are glued to the exterior molds using a mixture of methyl ethyl ketone (MEK) and ground up ABS plastic. For additional sealing a plastic welding process is used. A special welding gun melts the two surfaces to be welded and injects a stream of hot ABS into the joint, bonding the two surfaces. For the thicker water jackets, internal support is necessary between the water jacket and external skin. Several different methods have been tested. I-beams created from vacuum formed 2x4's are used inside the turret. Another internal support structural concept is using plastic rods drilled through both layers.

The glacis water jacket was the first thick water jacket to be built. The initial fill test showed evidence of leaks in various areas. These leaks were addressed with additional MEK solution and layers of fiberglass cloth adhered to the surface with MEK solution. The second fill test proved to be successful and the water jacket successfully held water. The surface temperature of the glacis was noticeably cooler to the touch than the fenders under direct solar loading at approximately 10:00. This initially demonstrates that the theory of water jackets is successful. The glacis, complete with water jacket, is shown in Figure 5.

Figure 5. Glacis water jacket testing.

Field test plans are developed to verify the results of the analyses and simulations, and to ensure structural integrity of the design prior to final prototype fabrication. The purpose of the field test is to measure and quantify any thermal differences between the actual and augmented plastic target. The goal is for the plastic surrogate to display passive thermal properties that emulate actual armor systems throughout the diurnal cycle. Thermocouple data will be sufficient for comparison between the actual, surrogate, and augmented surrogate. The instrumented vehicles will have data recorded as temperature vs. time. All vehicles will have to be measured simultaneously and the environmental histories of the vehicles will need to be identical. All test vehicles need to be at the test site a day in advance of the first measurements so that they reach thermal equilibrium with the local environment. The water jackets of the plastic target should be filled at least 24 hours prior to data collection to allow the water temperature to come to equilibrium with the surrounding environment. Initially, temperature data is used for comparisons of IR signature for the surrogate against the actual threat target. At first, only the glacis of each vehicle will be instrumented and tested to initially validate the process. Field testing of the entire vehicle will follow, with the addition of infrared image measurements for full validation.

SAMPLE RESULTS

Figure 6 displays the estimated mass calculations. The water jackets, when full, will add approximately an additional 4000 pounds to the current plastic surrogate. For transportation purposes, the water jackets will be drained and the mass of the target will not include the additional 4000 pounds. However, weight will also be gained from the additional wooden structure necessary for supporting the load of the water.

The combined output of the diurnal cycle simulations for three vehicles is displayed in Figure 7. An identical node on the glacis was selected for each of the three simulations. The temperature of that node throughout the diurnal cycle is recorded and graphed. The simulation begins prior to sunrise, and continues until that time the following day. The weather file used in obtaining these results was a sunny day on July 19, 1984, with latitude of 47.175 and longitude of 88.492. The approximate sunrise and sunset times are 6:17 and 21:43, respectively. The vehicle is positioned facing south. The dip at approximately time equals 8 hours is due to the shadow of the gun as it passes over the turret. This is very apparent on the plastic target due to the thin ABS material. This large temperature fluctuation is proof that the plain plastic target is insufficient in representing the thermal signature of an actual T-72. The effect created from the shadow shows how quickly the thin plastic cools off without the direct solar loading from the sun. The same is true for the heating effect caused by the impact of the solar radiation. These results show the selected node of the actual target and the water jacket target track fairly closely. The addition of a water jacket to the glacis creates about a 75% solution to achieving the correct thermal signature of an actual T-72. Similar graphs have been developed for each water jacket, all displaying an improvement in the signature from the plastic to the actual target.

Estimated Mass Calculations

Part Name	Armor Material	Armor Thick mm	Water Thick mm	in	Area in^2	Volume in^3	Mass lbs
Glacis	Laminate	200	200	8	5091	40728	1434
Hull Sides	Steel	60	52	2	2727	5454	192
Hull Top	Steel	30	24	1	2695	2695	95
Hull Rear	Steel	60	52	2	3024	6048	213
Turret Top	Steel	45	38	1.5	3522	5283	186
Turret Rear	Steel	120	108	4.25	2434	10345	364
Turret Front /	Laminate	250	229	9			
Turret Sides (2)	Steel	120	108	4.25			
			avg.	6.63	5154	34145	1202
Turret Top Sides	Steel	45	38	1.5	4964	7446	262

Figure 6. Estimated mass calculations.

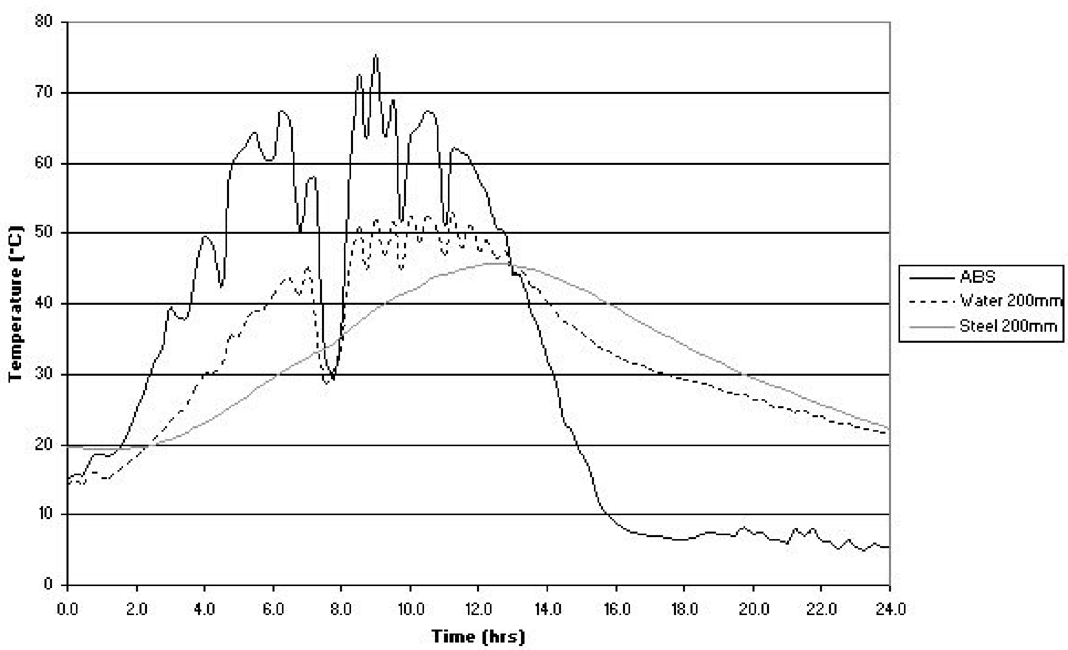

Figure 7. Glacis simulation results.

Two sets of sample results are displayed in Figure 8. The first row shows the targets at 10:25. This is approximately 4 hours after the sun initially hit the targets. As seen in the figure, the thicker areas of the glacis and turret of the real target are cool in contrast with the surrounding thinner parts. The plastic target is one homogeneous mass, lacking the internal thermal contrasts of the real target. The results for the target with water jackets are similar to those of the actual target. The water jackets delay the temperature increase from the morning sun for the thicker parts and are successful in mimicking the thermal imagery of the actual target.

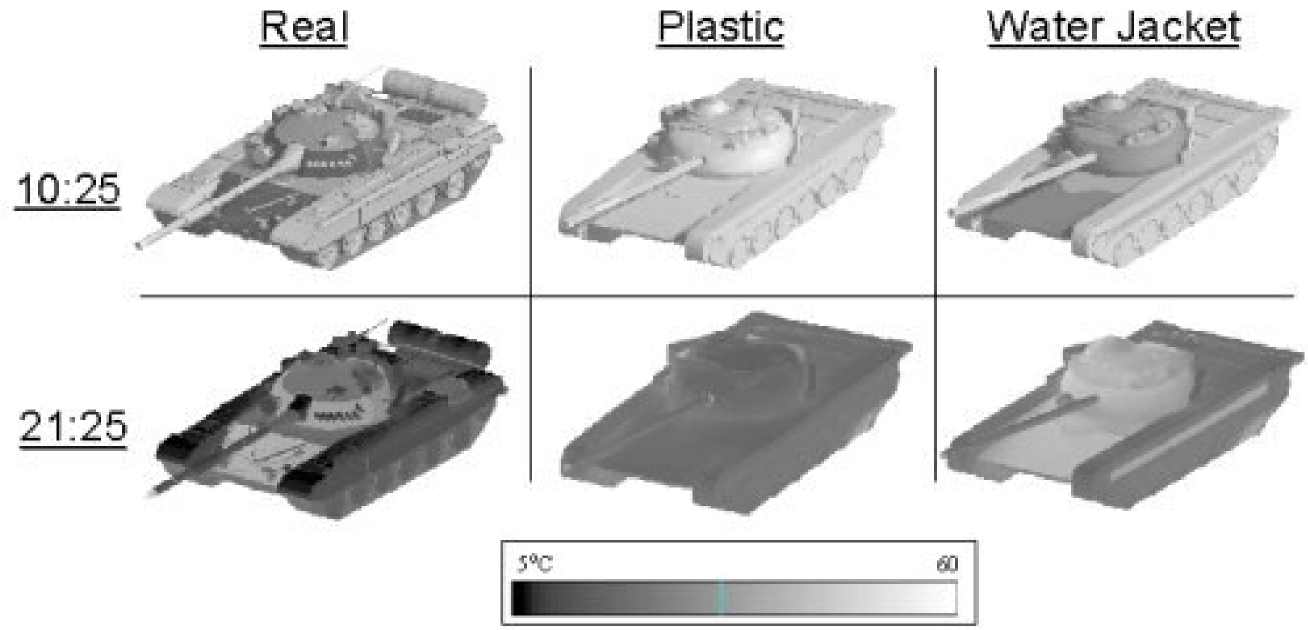

Figure 8. Sample thermal image results.

The second row shows the target at 21:25, right around sunset. The thinner sections of the real target have cooled down, but the thicker sections are still relatively warm. The same holds true for the target with water jackets. Once again, the plastic target is a homogenous mass that quickly cooled as the heat of the day decreased. These results demonstrate the utility of water jackets for plastic target IR signature augmentation.

The existing plastic target uses a wooden structure for the supporting framework. This is a fairly simplistic structure based on the fact that it only has to support the weight of the thin ABS plastic shell from which the target is manufactured. In order to support the additional weight incurred by the water jackets, it is necessary to design further support structures to withstand the load of each water jacket.

To achieve this goal, the initial framework is modified to support the larger load. The left side of Figure 9 shows the original support structure necessary to support the existing plastic T-72 ground target. Since there is a chance that people may be underneath the support structure, the structure is overbuilt to have a factor of safety of at least 2. Design selection is based on ease of assembly, supporting ability, and design simplicity. The middle of Figure 9 shows steps in the process of improving the framework. The right side of Figure 9 shows the initial supporting framework with some of the support structure additions. Each water jacket has a support structure designed to support the load of that jacket. The individual support is then integrated into the existing framework.

The augmented plastic target is intended for stationary usage only. In the event that the target has to be relocated, each of the water jackets will need to be drained. The momentum created with moving large masses of water could cause the rigid water jackets to crack and break. The surrogate target can be relocated on skids with empty water jackets much the same as the existing plastic targets.

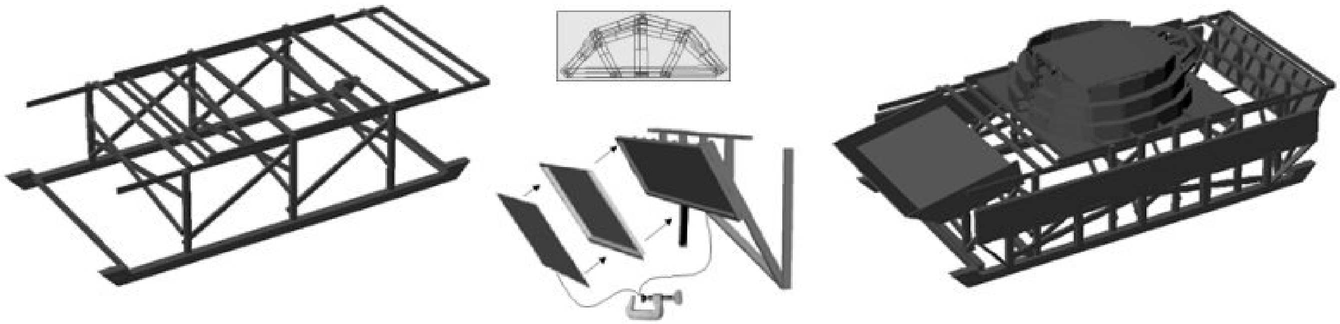

Figure 9. Additional supporting framework.

CONCLUSION

This paper presented the concept of using water enhanced plastic targets to satisfy TMO's needs for low-cost, full-scale, ground targets. With the addition of water jackets, the plastic target has a representative passive IR signature of an actual T-72 main battle tank. The results of the simulations presented here indicate that water jackets are a successful approach to improving the passive IR signature of the existing plastic ground target. Initial success in fabricating the water jackets and support structures indicate that the process is technically feasible. The simulation results verify the basic concept of using components with equivalent heat capacities for surrogate vehicle construction. With the addition of water jackets, the need for targets that can accurately simulate the visual and infrared signatures of threat systems has been met. The augmented plastic targets are fully capable of emulating infrared signatures of threat systems for use in destructive and non-destructive testing by the U.S. Army T&E community and there are vast opportunities for the usage of such targets.

REFERENCES

[1] Sanders, J.S., and Wible, W., "A Novel Method for Enhancing the Passive Infrared Signature of Target Surrogates", *Proceedings of the Sixth Annual Ground Target Modeling & Validation Conference*, Houghton, MI, August 1995.